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AREAS IN THE EASTERN REGION, ADAS, SUITABLE FOR THE ECONOMIC PRODUCTION OF GRAIN MAIZE

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1. INTRODUCTION

The request from ADAS advisers, for guidance on the location and characteristics of sites suitable for the economic production of grain maize can be used to demonstrate the role, the difficulties and the requirements of agricultural meteorologist in the field.

Primarily we are presented with a real life problem. Even in the absence of any comment by the meteorologist, experimentation, and trial and error studies will go on.

The time in which to produce a solution is short. We cannot now think in terms of further experiments lasting many years; rather answers must be made available before the end of the present harvest and the start to the new farming year.

In nominating an economic crop as one of 45 cwts per acre (at 15% moisture content - wet weight basis) in most years we are in effect being forced into requirement for quantitative relations between weather and crop growth (and the more difficult problem of quantitative relations between weather and crop yield). We know that some people have spent a life time studying these problems and yet theoryremains inadequate. The various models of crop growth currently available invariably involve detailed statements of environmental parameters in the boundary layer (which can only be obtained, at the requisite frequency, by considerable instrumentation). Equally we are aware that where detailed physical reasoning has been avoided, and when correlation techniques using crude weather data have been used, the results have not usually been satisfactory in climates, such as that of the UK, where any single weather element is seldom limiting to crop growth in every season.

With theory and meteorological data both unsatisfactory, our difficulties are not yet over. The biological data also has some inherent uncertainty, due not least to the effects of weather dependent pest and disease and husbandry techniques. To emphasise this point one need only quote the results of grain maize trials in the South East Region in 1971, viz

County		Yield (at 85% dry matter)
West Sussex	Field 1	37.4 cwts/acre
	2	57.2
	3	53.4
	4	31.2
	5	33.6
Hants	1	15.1
	2	38.7

It is unlikely that weather differences alone over an area the size of a county could account for differences in yield of the order 2 to 1.

As scientists we might not be prepared to attempt an answer to the initial question; as technologists, we are required to produce working solutions, within a short time, and in a form which can be understood and used directly by ADAS advisers, without any further manipulation on their part, and with only the minimum of supplementary field data in specific situations.

2. A RELATIONSHIP BETWEEN WEATHER FACTORS AND YIELDS OF GRAIN MAIZE

The effects of weather on the yield of maize in the UK has been examined by Hough (Ag Mem 385, 386). It was assumed that this study identified most of the important weather factors and that any quantitative relations could be restricted to the parameters considered by Hough provided these were extended to include the month of September. The data for 11 years results at Oxford were re-examined.

In the work now reported, the view was taken that the growing season should be divided into pre-flowering and post flowering periods, and that in determining final yields, the effects of the two periods should be multiplied rather than simply accumulated.

For the variety used in the Oxford trials (INRA 200) it was assumed that the season with the highest reported yield represented the optimum conditions, and that yields in the remaining seasons should be considered in terms of departures from these optimum conditions.

The pre-flowering weather parameters finally settled on were

May - mean daily maximum temperature (deg C) - (T_1)
June - total radiation (on a horizontal surface) - (R_1)
ie mean daily value for the month (m w hr cm $^{-2}$)
July - total radiation (mean daily values) - (R_2)
and the post-flowering weather parameter was essentially
(August + September) - total radiation (Mean daily values) - (R_3)

However since there is no 1 to 1 relationship between solar radiation and air temperatures at crop level it was found convenient to introduce, as a control, the requirements that the accumulated air temperature (daily mean values in excess of 10°C) should lie within a certain broad ranges over both the pre-flowering and post flowering periods if crop yields were not to suffer (even though radiation values themselves did not appear inadequate).

With weather factors specified interms of departures from some nominated value, both a deficit and an excess of radiation for example lead to a decrease in yield and the relationships we imply are parabolic, rather than linear.

The final expression for yield took the form.

$$Y = K\left[\left(\frac{15.5}{15.5 + \left|T_1 - 15.5\right|}\right) + \left(1 - \left|\frac{R_1 - 520}{520}\right|\right) + \left(1 - \left|\frac{R_2 - 515}{515}\right|\right)\right]\left[f_1(T)\right] \times \left[1 - \left|\frac{R_3 - 655}{655}\right|\right]\left[f_2(T)\right]$$

where Y = uield of grain dry matter (cwts/acre) ie 100% dry matter
K = constant

Let $T_{(a)}$ = daily accumulated air temperature, above 10°C, over the months of May, June and July.

If $T_{(a)} \geq 330$ degree days, then $f_1(T) = 1$

If $T_{(a)} < 330$ degree days, than $f_1(T) = (T_{(a)}/380)$

Let $T_{(b)}$ = daily accumulated air temperature, above 10°C, over the months of August and September.

If $T_{(b)}$ lies in the range 360 ± 50 degree days, then $f_2(T) = 1$

If $T_{(b)} < 310$ degree days, then $f_2(T) = (T_{(b)}/360)$

If $T_{(b)} > 410$ degree days, then $f_2(T) = \left[1 - \left| \frac{T_{(b)} - 410}{410} \right| \right]$

Applying this expression to the 1967 data (the best season at Oxford) gave K a value of 18.3

The results of the remaining seasons data at Oxford are as follows

Year	Predicted Yield	(100% Dry) matter	Actual Yield	Predicted Yield / Actual Yield
1967	54.8	cwts/acre	54.8	1.0
1969	48.4		51.0	.95
1958	43.7		45.9	.95
1964	41.6		43.3	.95
1961	48.3		41.6	1.16
1959	40.1		41.4	.97
1970	42.2		44.0	.96
1960	38.1		43.5	.84
1966	45.8		46 4	.99
1968	39.3		37.4	1.05
1965	31.9		30.7	1.03

In 9 of the 11 seasons data, the forecast yield is within 5% of the actual. The correlation coefficient between predicted and actual yield is .88.

3. APPLICATION OF YIELD/WEATHER RELATIONSHIP TO THE EASTERN REGION

3.1 TO CAMBRIDGE

The expression reported in the previous section was applied to the sample of data available from the NIAB Cambridge with the following results.

Year	Predicted Yield (100% Dry) matter	Actual Yield	Predicted Yield / Actual Yield
1960	38.2 (45.0) cwts/acre	34.3 (40.4)	1.11
1961	48.9 (57.5)	30.3 (35.7)	1.61
1963	16.0 (18.8)	13.4 (15.8)	1.19
1964	39.2 (46.1)	41.3 (48.6)	.95
1965	32.7 (38.4)	15.3 (18.0)	2.13
1966	39.3 (46.2)	33.5 (39.4)	1.15
1967	53.5 (63.0)	36.7 (42.0)	1.50
1969	42.6 (50.1)	39.7 (46.6)	1.07

( ) indicates yield at 85% DM

The correlation coefficient between predicted and actual yield is .72

One could attempt to improve this correlation coefficient by, for example, modification of the figures for the years where large losses were known to have occurred from birds and rats. There seems little point in doing this. Obviously the Oxford data are a more coherent sample than the Cambridge data. The Cambridge result is perhaps a little disappointing, but on reflection, since predicted yields at Cambridge are almost invariably greater than actual yields, it might be argued that the expression developed gives potential yields under relative freedom from pest and disease and a satisfactory husbandry practice. In the absence of detailed information on pests and disease, one can only proceed on the assumption that reported yields reflect direct weather effects, and that indirect weather effects (eg on pests and disease) produce second order effects on yield. This assumption is known not to be true in particular situations and obviously the effects of pests and disease are relevant to any study of the economic cropping of maize, .However, pests and disease are presumably subject to control and susceptable to field hygiene, whereas as the weather and climate elements of interest here, are not. It is on these latter elements that we have to concentrate, and there seems little alternative but to proceed on the supposition that the relationship based on Oxford weather and yields is the best we are likely to achieve, and to examine its implications for the Eastern Region generally.

3. APPLICATION OF THE YIELD/WEATHER RELATIONSHIP TO THE EASTERN REGION

3.2 GENERALLY

In most years the Oxford yield/weather relationship series predicted yields within 5% of those observed. An economically worthwhile crop (in the future) has been set at 45 cwts/acre (at 85% Dry matter). We now attempt to identify those areas in the Eastern Region where predicted yields of (45 cwts + 5% 45 cwt) = 47.5 cwt (at 85% Dry Matter) might consistently be achieved. To do this involves an examination of the sensitivity of the yield/weather relationship and the variability of the nominated weather elements from season to season. We assume Cambridge to be typical of the Region.

We examine first the characteristics of successful seasons at Cambridge and then identify areas in the Region where these characteristics would generally be met.

The choice of consistently good area for cropping is taken to imply that low day degree accumulations will never be limiting, and since we know we are near the northern limit for economic cropping, we assume that high degree day accumulations will not depress yields to any significant extent and that we may write

$$f_1(T) = f_2(T) = 1$$

For the long period average year at Cambridge, we find

$$\frac{15.5}{15.5 + \left| T_1 - 15.5 \right|} = .900$$

$$1 - \left| \frac{R_1 - 520}{520} \right| = .960$$

$$1 - \left| \frac{R_2 - 515}{515} \right| = .880$$

$$1 - \left| \frac{R_3 - 655}{655} \right| = .968$$

and the expected yield = 48.6 cwts/acre (DM @ 100%)
= 52.2 cwts/acre (DM @ 85%)

Over a typical 11 year sample, at Cambridge, for which radiation data were available we find the ranges of these quantities, alone and in combination to be as follows.

PARAMETER	RANGE
$\frac{15.5}{15.5 + \lvert T_1 - 15.5 \rvert}$	.790 to .990 (Max possible value = 1)
$1 - \left\lvert \frac{R_1 - 520}{520} \right\rvert$	.800 to .980 (Max possible value = 1)
$1 - \left\lvert \frac{R_2 - 515}{515} \right\rvert$	.735 to .996 (Max possible value = 1)
$\left[\left(1 - \left\lvert \frac{R_1 - 520}{520} \right\rvert \right) + \left(1 - \left\lvert \frac{R_2 - 515}{515} \right\rvert \right) \right]$	1.605 to 1.976 (Max possible value = 2)
$\left[\left(\frac{15.5}{15.5 + \lvert T_1 - 15.5 \rvert} \right) + \left(1 - \left\lvert \frac{R_1 - 520}{520} \right\rvert \right) + \left(1 - \left\lvert \frac{R_2 - 515}{515} \right\rvert \right) \right]$	2.506 to 2.966 (Max possible value = 3)
$1 - \left\lvert \frac{R_3 - 655}{655} \right\rvert$	.832 to 1.000 (Max possible value = 1)

POST FLOWERING WEATHER AS A DISCRIMINANT

We set the pre-flowering weather parameter (in our yield/weather relationship) to have the minimum observed numerical value of the 11 year sample of seasons at Cambridge, (and equal to 2.506).

We note that a yield of 47.5 cwts at 85% Dry Matter implies 40.4 cwts/acre Dry Matter.

Substition in the numerical expression for yield

$$40.4 = 18.3 \times 2.506 \times \left(1 - \left\lvert \frac{R_3 - 655}{655} \right\rvert \right)$$

from which $\left(1 - \left\lvert \frac{R_3 - 655}{655} \right\rvert \right)$ must be $\geq .87$

for a yield $\geq$ 40.4 cwts/acre Dry Matter

and R_3 = Sum of monthly mean daily values of radiation for August and September

R_3 = 570 or 740 m w hrs cm^{-2}

We note that

(i) the probability (p) of the pre-flowering weather elements giving rise to a numerical value $\geq$ 2.505 is p = 1

(ii) our 11 year sample of data suggests that the probability (p) of the post-flowering weather elements giving rise to a numerical value $\geq$ 0.87 is p = (9/11)

(iii) over a typical sample of years at Cambridge, a lower limit to the quantity R_3 is given by the average value of R_3 minus 100 mw hr cm^{-2}

Accordingly we suggest that for the yield we have specified ($\geq$ 47.5 cwts/acre at 85% DM, in most years) that suitable conditions in the post-flowering period will be found in areas where the average value of R_3 is 570 + 100 = 670 mw hr cm^{-2} or more.

For practical purposes we suggest that with post-flowering weather as a discriminant suitable areas will be bounded by the isopleth R_3 = 675 mw hr cm^{-2} on long period average maps.

PRE-FLOWERING WEATHER AS A DISCRIMINANT

The minimum observed numerical value of the post-flowering weather parameter (in our yield/weather relationship) for the 11 year sample at Cambridge is 0.832.

Taking again a nominated yield of 40.4 cwts/acre dry matter, then a substitution of these values in our expression gives

$$40.4 = 18.3 \times (\text{pre-flowering weather factor}) \times .832$$

from which (pre flowering weather factor) must be $\geq$ 2.65 for a yield $\geq$ 40.4 cwts/acre in every year.

The minimum contribution of the May temperature to the pre-flowering weather factor is 0.79, from which we infer the contribution from radiation in June and July must be at leat 1.86 in every year. To achieve this, the combined monthly mean daily values for June and July must be of the order 960-970 mw hr cm^{-2},

[The average value for Cambridge is 948 mw hr cm^{-2}]

We note that

(i) the probability (p) of the post flowering weather elements giving rise to a numerical value $\geq$ .83 is p = 1

(ii) our 11 year sample of data suggests that the probability (p) of the pre-floweri weather elements giving rise to a numerical value $\geq$ 2.65 is p = (6/11) at Cambridge

(iii) over a typical sample of years at Cambridge, a lower limit to the combined monthly, mean daily values of total radiation for June and July, is given by the average value of this quantity minus 90 mn hr cm^{-2}.

We therefore suggest that for the yield we have specified ($\geq$ 47.5 cwts/acre at 85% DM in most years) that suitable conditions in the pre-flowering periods will be found in areas where the average value of the sum of the monthly mean daily values of total radiation in June and July is 960 + 90 = 1050 mw hr cm^{-2} or more.

Repeating the calculations and arguments for a value of the post flowering weather parameter equal to 0.86 (a value achieved or exceeded in 10 years out of the 11 year sample) leads to suitable conditions in the pre-flowering period being identified as these area on average maps bounded by the isopleth 1000 mw hr cm^{-2} [for the sum of June and July radiation - monthly mean daily values].

COMBINATION OF THE PRE AND POST FLOWERING WEATHER REQUIREMENT

Examination of average maps of radiation (Day 1961) shows that the pre-flowering requirement is the more restructive and may be used as the sole discriminant to identify suitable growing areas.

Such a map is shown in figure 1

4. THE EFFECT OF SLOPE AND ASPECT IN EXTENDING THE AREA CONSIDERED SUITABLE FOR ECONOMIC CROPPING

It can be shown that for slopes suitable for arable cropping, (up to 20° from the horizontal say) that their effects are minimal in increasing the intercepted radiation on the average, cloudy day at Cambridge.

Indeed for aspects other than the most favourable facing south intercepted (total/global) radiation may be below that falling on a horizontal surface.

The areas suitable for the economic cropping of maize are not to be extended westwards to any extent on account of slope and/or aspect.

Meteorological Office
Cambridge

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REFERENCES

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Mean Daily Values of Total Radiation on a Horizontal Surface mw. hr. cm^{-2}